10

Tropical Cyclones

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Background and Nature of Tropical Cyclones

Tropical cyclones are among the most destructive weather systems *(1–3)*. The impact from cyclones generally extends over a wide area, with mortality, injury, and property loss that result from strong winds and heavy rains. Often secondary events such as storm surges, flooding, landslides, and tornadoes exacerbate effects of these systems *(4)*. Although improved warning systems in most cyclone-prone areas of the world today prevent or reduce deaths, meteorological elements, increased population growth, and the development of human settlements along coastal areas continue to present risks associated with cyclone-related mortality and morbidity.

Tropical cyclones are meteorological depressions, or low pressure systems, that develop over open water in the tropics, usually between the latitudes of 30° N and 30° S *(5)*. They originate at locations where an unstable atmosphere causes differences in the amount of energy received by the earth's poles. A rotating disturbance forms around a center of calm atmosphere, or *eye*, usually 30–50 kilometers in diameter, with air circulating counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. From energy obtained through oceanic evaporation, cyclones may move at speeds of 10 to 50 kilometers per hour within the zone of trade winds *(1)*. Each year about 80 tropical cyclones with an average duration of 9 days develop, travel a distance of over 10, 000 kilometers, and then lose force overland *(1, 5)*. Known as *hurricanes* in the North Atlantic, Caribbean Gulf, eastern north Pacific, and western coast of Mexico, they are called *typhoons* in the western Pacific and *cyclones* in the Indian Ocean and Australasia *(5)*.

The life cycle of tropical cyclones consists of development, intensification, maturity, decay, or modification *(6)*. In this cycle, tropical cyclones may originate from *subtropical cyclones*, defined as low-pressure systems over tropical waters. As they develop, other tropical cyclones may lose their tropical characteristics altogether and become *extratropical cyclones*, or "*nor'easters*" *(6)*.

By definition, a tropical cyclone is a term assigned to cyclonic circulations that originate over tropical waters *(7)*. A circulation is further classified by the following levels and may be upgraded or downgraded at any time, depending on form and intensity: (1) tropical wave; (2) tropical disturbance; (3) tropical depression; (4) tropical storm; and (5) hurricane, typhoon, or cyclone *(8)*. Table 10-1 lists the definitions of each of these terms. In the United States, hurricanes are ranked on the Saffir/Simpson Hurricane Scale, which relates hurricane intensity to damage potential. The scale accounts for size, coastal configuration, astronomical tides, terrain features, urbanization, and industrialization *(6)*. The conditions for wind speeds and storm surges that describe each storm category are shown in Table 10-2.

Scope and Relative Importance of Tropical Cyclones

Worldwide, 150 million people were affected by cyclones from 1967 to 1991. Of these tropical cyclones an estimated 900 killed approximately 900, 000 people and injured more than 240, 000 *(2)*. In the United States during this century, hurricanes have resulted in more than 14, 600 deaths and have caused property damage of more than $94 billion, when adjusted to 1990 dollars *(9)*. In the continental United States, an annual average of two hurricanes develops sufficiently to make landfall on the coastline of the Atlantic and the Gulf of Mexico *(8)*, although many more develop in the course of a year, as shown in Table 10-3 *(6)*. The National Weather Service estimates that of approximately 70 million people at risk from hurricanes, 50 to 100 people on average are killed per

Table 10-1 Definitions of Tropical Cyclonic Circulations

Tropical wave	A trough of low pressure in the trade-wind easterlies.
Tropical disturbance	A moving area of thunderstorms in the tropics that maintains its identity for 24 hours or more.
Tropical depression	A tropical cyclone in which the maximum sustained surface wind is 38 miles per hour (33 knots*) or less.
Tropical storm	A tropical cyclone in which the maximum sustained surface wind ranges from 39 to 73 miles per hour (34–63 knots).
Hurricane	A tropical cyclone in which maximum sustained surface wind is 74 mph (64 knots) or greater.

*A knot is one nautical mile per hour; a nautical mile is approximately 1.15 statute miles.

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service (8).

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Table 10-2 The Saffir/Simpson Hurricane Scale*

Category	*Description*
1	Winds 74–95 miles per hour Damage primarily to shrubbery, trees, foliage, and unanchored mobile homes. No damage to other structures. Some damage to poorly constructed signs. Storm surge 4–5 feet above normal Low-lying coastal roads inundated, minor pier damage, some small craft in exposed anchorage torn from moorings.
2	Winds 96–110 miles per hour Considerable damage to shrubbery and tree foliage; some trees blown down. Major damage to exposed mobile homes. Extensive damage to poorly constructed signs. Some damage to roofing materials of buildings; some window and door damage. Storm surge 6–8 feet above normal Coastal roads and low-lying escape routes inland cut by rising water 2 to 4 hours before arrival of hurricane center. Considerable damage to piers. Marinas flooded. Small craft in unprotected anchorages torn from moorings. Evacuation of some shoreline residences and low-lying island areas required.
3	Winds 111–130 miles per hour Foliage torn from trees; large trees blown down. Practically all poorly constructed signs blown down. Some damage to roofing materials of buildings; some window and door damage. Some structural damage to small buildings. Mobile homes destroyed. Storm surge 9–12 feet above normal Serious flooding at coast and many smaller structures near coast destroyed; larger structures near coast damaged by battering waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Flat terrain 5 feet or less above sea level flooded inland 8 miles or more. Evacuation of low-lying residences within several blocks of shoreline possibly required.
4	Winds 131–155 miles per hour Shrubs and trees blown down; all signs down. Extensive damage to roofing materials, windows, and doors. Complete failure of roofs on many small residences. Complete destruction of mobile homes. Storm surge 13–18 feet above normal Flat terrain 10 feet or less above sea level flooded inland as far as 6 miles. Major damage to lower floors of structures near shore due to flooding and battering by waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Major erosion of beaches. Massive evacuation of all residences within 500 yards of shore and of single-story residences on low ground within 2 miles of shore possibly required.
5	Winds greater than 155 miles per hour Shrubs and trees blown down; considerable damage to roofs of buildings; all signs down. Very severe and extensive damage to windows and doors. Complete failure of roofs on many residences and industrial buildings. Extensive shattering of glass in windows and doors. Some complete building failures. Small buildings overturned or blown away. Complete destruction of mobile homes. Storm surge greater than 18 feet above normal Major damage to lower floors of all structures less than 15 feet above sea level within 500 yards of shore. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Massive evacuation of residential areas on low ground within 5 to 10 miles of shore possibly required.

*Conditions for wind speeds and/or storm surge determine the category of a hurricane.

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, National Environmental Satellite Data, and Information Service. *(6)*

Table 10-3 Frequency of Hurricanes Making Landfall in the United States by Saffir-Simpson Category, 1982—1992

	Category						
Area	*1*	*2*	*3*	*4*	*5*	*All*	*Major Hurricanes ≥ 3*
United States (Texas to Maine)	11	7	9	2	0	29	11
Texas							
North	3	0	1	0	0	4	1
Central							
South							
Louisiana	3	0	1	0	0	4	1
Mississippi	0	0	1	0	0	1	1
Alabama	0	0	1	0	0	1	1
Florida							
Northwest	0	1	1	0	0	2	1
Northeast							
Southwest	1	0	1	0	0	2	1
Southeast	0	0	0	1	0	1	1
Georgia							
South Carolina	1	0	0	1	0	2	1
North Carolina	1	0	2	0	0	3	2
Virginia	1	0	0	0	0	1	1
New York	0	1	1	0	0	2	1
Connecticut	0	2	0	0	0	2	0
Rhode Island	0	1	0	0	0	1	0
Massachusetts	0	1	0	0	0	1	0
New Hampshire	0	1	0	0	0	1	0
Maine	1	0	0	0	0	1	0

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, National Environmental Satellite Data, and Information Service. *(6)*

event, with property losses in the billions of dollars during a worse-than-average hurricane season *(9)*. The impact of Hurricane Andrew in Florida alone amounted to $25 billion in 1992 *(10)*.

Factors that Contribute to Tropical Cyclone Problem

Despite massive mortality and morbidity worldwide, early detection and warning systems leading to evacuation and sheltering have helped to reduce or prevent deaths in many areas, notably in the United States, the Caribbean countries, and the coastlines of Central and South America. In other countries, such as Bangladesh and the Philippines, technology to forecast storms is relatively modern and accurate; however, timely

ıe United States by Saffir-Simpson

4	5	All	Major Hurricanes ≥ 3
2	0	29	11
0	0	4	1
0	0	4	1
0	0	1	1
0	0	1	1
0	0	2	1
0	0	2	1
1	0	1	1
1	0	2	1
0	0	3	2
0	0	1	1
0	0	2	1
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0	0	1	0
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evacuation and safe sheltering have yet to improve for vast numbers of inhabitants in vulnerable areas *(11, 12)*.

In the United States, mortality peaked at 6,000 in the hurricane of 1900 in Galveston, Texas, and declined over the decades to 256 when Hurricane Camille struck the Gulf Coast and the Virginias in 1969 (see Table 10-4). In most instances, drowning from storm surges accounted for the majority of these deaths. Thereafter, the National Weather Service developed a forecasting model called the "Sea, Lake, and Overland Surges from Hurricanes," or SLOSH model, to compute storm surge from hurricanes *(13, 14)*. Because the models determine patterns of flooding and thus predict the most vulnerable areas to a hurricane's forces, occupants can be evacuated safely before a hurricane's landfall in areas subject to hazardous inundation *(14)*. For instance, advanced preparation, including the evacuation of more than 350, 000 people, in Alabama before Hurricane Frederic in 1979 resulted in a low death toll of 5 people for this event *(15)*. After Hurricane Andrew struck southeastern Florida in 1992, however, several deaths occurred outside inundation and evacuation zones and were attributed to winds that may have been unique to this disaster *(10)*. Wind-related issues are presently being incorporated into a comprehensive national hurricane program *(10)*.

Like most natural disasters, the nature of cyclones requires continued observation of their effects on public health and safety well into the response and recovery phases. Latent effects are often typified by deaths and injuries, such as electrocutions from loose or wet wiring, cleanup injuries, and burns from unattended flames *(16–18)*. Furthermore, surveillance of endemic illnesses and infectious diseases heralds the occurrence of epidemics that may arise, particularly after hydrometeorological disasters. Knowledge of these effects and others have yet to be reinforced and investigated, and appropriate public health strategies have yet to be devised.

Factors Affecting Tropical Cyclone Occurrence and Severity

Although property damage has increased considerably, deaths and injuries associated with tropical cyclones have been prevented or reduced in recent decades, largely because of improved forecasting, warning, evacuation, and sheltering of communities at risk. However, the hazards associated with tropical cyclones continue to present problems for public health, emergency management, and meteorological forecasting.

Meteorological events elsewhere in the world can precede the occurrence of tropical cyclones in a given region. The *frequency* of major hurricanes off the coast of the southeastern United States has been found to correlate with the wet and dry phases of rainfall in West Africa *(19)*. Of more than 100 tropical disturbances that develop in the Atlantic, the Caribbean, and the Gulf of Mexico in any given year, an estimated 10 become tropical storms, of which 6 mature into hurricanes. On the average, 2 of these hurricanes directly hit the United States annually *(8)*.

Table 10-4 Hurricane Events with Mortality ≥25 Deaths in the United States, by Saffir-Simpson Category, 1900–1992

Hurricane	*Year*	*Category*	*No. of Deaths*
1. Texas (Galveston)	1900	4	6,000
2. Florida (Lake Okeechobee)	1928	4	1,836
3. Florida (Keys)/South Texas	1919	4	600*
4. New England	1938	3†	600
5. Florida (Keys)	1935	5	408
6. Audrey (Southwest Louisiana/North Texas)	1957	4	390
7. Northeast United States	1944	3†	390‡
8. Louisiana (Grand Isle)	1909	4	350
9. Louisiana (New Orleans)	1915	4	275
10. Texas (Galveston)	1915	4	275
11. Camille (Mississippi and Louisiana)	1969	5	256
12. Florida (Miami)	1926	4	243
13. Diane (Northeast US)	1955	1	184
14. Southeast Florida	1906	2	164
15. Mississippi/Alabama/Florida (Pensacola)	1906	3	134
16. Agnes (Northeast US)	1972	1	122
17. Hazel (South Carolina/North Carolina)	1954	4†	95
18. Betsy (Southeast Florida/Southeast Louisiana)	1965	3	75
19. Carol (Northeast US)	1954	3†	60
20. Southeast Florida/Louisiana/Mississippi	1947	4	51
21. Donna (Florida/Eastern US)	1960	4	50
22. Georgia/South Carolina/North Carolina	1940	2	50
23. Carla (Texas)	1961	4	46
24. Texas (Velasco)	1909	3	41
25. Texas (Freeport)	1932	4	40
26. South Texas	1933	3	40
27. Hilda (Louisiana)	1964	3	38
28. Southwest Louisiana	1918	3	34
29. Southwest Florida	1910	3	30
30. Connie (North Carolina)	1955	3	25
31. Louisiana	1926	3	25

*Of 600–900 deaths, over 500 occurred among persons who were thought to be lost on ships at sea.

†Moving more than 30 miles an hour.

‡An estimated 344 were lost on ships at sea.

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. *(8)*

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	3†	600
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	4	275
	4	275
	5	256
	4	243
	1	184
	2	164
	3	134
	1	122
	4†	95
	3	75
	3†	60
	4	51
	4	50
	2	50
	4	46
	3	41
	4	40
	3	40
	3	38
	3	34
	3	30
	3	25
	3	25

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Administration, National Weather Service. *(8)*

Tropical cyclones have seasonal patterns in many regions of the world. In the Caribbean and the Pacific, hurricanes occur between June and November when atmospheric conditions are conducive to their development *(8)*. However, severe storms have been known to take place outside this period. In the Indian Ocean, cyclones normally occur during early summer (April–May) or late rainy season (October–November) when low atmospheric pressures favor their birth *(20)*. However, they have been known to strike the southern coast at any time between April and December *(21)*.

Elements that constitute tropical cyclones can lead to direct or indirect injuries or damages to humans and dwellings. Winds with velocities of as much as 210 miles per hour (336 kilometers per hour) cause structural collapse and force debris to be hurled through the air as high-velocity projectiles *(9)*. Accompanying torrential rains, as much as 30 inches in several days, can generate flash flooding and mudflows *(5, 9)*. Storm surges, the abnormal rising of water generated by a storm over and above the predicted astronomical tide, have been observed up to 25 feet in height; they typically last for several hours and generally affect an estimated 100 miles of coastline *(9, 15)*. Flooding occurs as strong winds or tides push sea waves created by a cyclone up the coastlines with destructive force. These storm surges are differentiated from *tsunamis*, which are seismic sea waves produced by movement of the earth's crust on the ocean's floor. Inland, cyclones can also prompt backwater surging in estuaries of water streams *(5)*.

Tropical cyclones may also be accompanied by secondary disasters that can create or exacerbate new or existing hazards. Under appropriate meteorological conditions, tornadoes can be created by hurricanes. The violent winds and erratic paths of hurricane-spawned tornadoes may require extraordinary responses on the part of the disaster-affected community *(10)*. Other secondary disasters, such as landslides or mudslides, also have the potential to develop. In October 1985, tropical storm Isabel caused widespread flooding and landslides in Puerto Rico; 127 deaths, 78 percent of all storm-related deaths, occurred in one landslide *(22)*.

Public Health Impact: Historical Perspective

The public health impact of cyclones has been examined in the context of the development of warning and forecasting systems. Before the introduction of warning systems that can result in timely evacuation and sheltering, drowning from storm surge accounted for an estimated 90 percent of all cyclone-related deaths *(5, 23)*. This percentage remains much the same today in areas where cyclone forecasting and warning, although improved, have yet to be disseminated to all public sectors. This pattern of death continues, for example, in Bangladesh and the Philippines, where other factors, such as inadequate housing and population density, exacerbate risks for drowning from storm surge *(24, 25)*.

Cyclone-related morbidity generally includes trauma, gastrointestinal illnesses, and

dermal conditions *(17, 18, 22, 26–29)*. Structural collapse and wind-strewn debris account for many of the injuries observed during a tropical cyclone. In particular, blunt trauma due to structural collapse may cause mortality during the impact phase; occupancy of mobile homes was implicated in the deaths of several people after Hurricane Andrew in Florida *(30)*.

In areas where warning systems effectively interface with scientific forecasting and emergency management, such as in developed countries, community activities undertaken during the preparedness, response, and recovery phases are frequently associated with actions undertaken during the preparedness, response, and recovery phases. Data from hospital-based surveillance of people with cyclone-related conditions treated in emergency departments indicate that circumstances for mortality and morbidity differ for pre- and postimpact phases. For example, injuries and deaths related to attempts to secure potential projectile objects have been observed before a hurricane's landfall; deaths from falling trees, trauma related to use of chain saws, and burns from unattended flames and generators are commonly reported in the aftermath of a cyclone. Heart attacks, attributed to stress, are also observed during this time *(27)*.

Infectious Diseases

Concern about potential epidemics from infectious diseases generally arises after a disaster. Usually, the risk for increased communicable disease is affected by six conditions: (1) changes in preexisting levels of disease, (2) ecological changes as a result of the disaster, (3) population displacement, (4) changes in population density, (5) disruption of public utilities, and (6) interruption of basic public health services (31). However, with the exception of a malaria outbreak after Hurricane Flora in Haiti in 1963, few serious epidemics of infectious diseases have been documented after tropical cyclones *(32, 33)*. Despite the lack of disease outbreaks to date, the potential for communicable disease exists in situations where sanitation and hygiene are compromised by changes in the environment incurred during the disaster.

In past hurricanes surveillance systems have been implemented to monitor communicable diseases, injuries, and other hurricane-related conditions. According to information from hospital emergency departments and care sites in both active and passive surveillance systems, serious disease outbreaks have yet to be documented during surveillance periods lasting as much as 1 month after a hurricane's impact *(17, 18, 22, 26, 34)*.

One study, however, showed a delayed increase in the incidence of typhoid and paratyphoid fever, infectious hepatitis, gastroenteritis, and measles after Hurricanes David and Frederick in the Dominican Republic on August 31 and September 3, 1979, respectively *(35)*. In another study, diarrheal morbidity rose by 17-fold during the 6 weeks after the cyclone in Bangladesh in 1991. The latter increase, however, was attributed to changes in reporting methods by the Bangladesh National Diarrhea Surveillance System *(36)*. Nevertheless, enteric and respiratory agents may contribute to

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the overall morbidity observed after cyclones. And because index conditions including gastrointestinal illnesses, respiratory illnesses, and dermal conditions make up the majority of postcyclone morbidity, they continue to be monitored after such events *(17, 22, 26)*.

Finally, the potential for vector-transmitted diseases may be exacerbated by a cyclone *(37)*. Human exposure to disease vectors may increase due to a damaged physical environment and due to migration to vector-borne-disease endemic areas (e.g., malaria and dengue). In addition, rains related to a cyclone may provide a breeding ground for nuisance mosquito populations. After Hurricane Andrew in Florida, emergency surveillance for mosquito-borne diseases such as St. Louis encephalitis, dengue, and malaria showed no marked increase, but in Louisiana, mosquito control was implemented for large nuisance populations that hampered disaster-recovery efforts after Hurricane Andrew *(37)*.

Animal Bites and Stings

Ecological disruptions after a cyclone may lead to changes in the natural habitat of wild animals. After Hurricane Hugo struck South Carolina in 1989, insect stings accounted for 21% of all hurricane-related cases that were treated inland; of these cases, 26% of people experienced generalized reactions *(38)*. Insect stings as a major source of morbidity were thought to result from destroyed insect nests caused by downed trees, the time of year in which the hurricane occurred (i.e., coincidental with the maturity phase of many species of biting or stinging insects), and the proximity of insects to people during cleanup activities. In areas where mosquito populations may increase as a result of storm-associated rains, secondary bacterial infections from mosquito bites may also occur, although no problem has been observed to date *(37)*.

Nutrition and Birth Defects

Long-term health outcomes due to a compromised nutritional status in the aftermath of hurricanes have been reported in the literature. The incidence of neural-tube defects (i.e., spina bifida cystica and encephalocele) among live-born infants increased in Jamaica 11 to 18 months after Hurricane Hugo occurred in 1988 *(39)*. The rise coincided with megaloblastic changes in sickle-cell patients at the time of conception and suggested a deficient intake of dietary folate.

Mental Health

As in most natural disasters, short- and long-term mental health effects are observed as long as 5 years after a hurricane's impact. Outcomes such as emotional and physical

distress, nonpsychotic psychological disturbances, and post-traumatic stress disorders have been found in different subgroups of the population *(40)*. In one case study, psychological disturbances were documented in cyclone evacuees after Cyclone Tracy swept through Darwin, Australia, in 1974 *(41, 42)*. Post-traumatic stress disorder was observed among adolescents 1 year after Hurricane Hugo struck South Carolina *(43)*. A population-based study among these adolescents indicated the following risk factors for post-traumatic stress disorder: (1) exposure to the hurricane, (2) prior experience with violent trauma, (3) ethnicity (i.e., being white), and (4) gender (i.e., being female) *(43)*. Finally, increased mental problems were described during a 5-year period after Hurricane Agnes brought widespread flooding to Pennsylvania in 1972 *(44)*. (Psychosocial factors are further discussed in Chapter 6, "Mental Health Consequences of Disasters".)

Factors Influencing Mortality and Morbidity

Early epidemiologic studies focused primarily on descriptive accounts of deaths and injuries after cyclones, particularly as they related to accompanying storm surges, heavy rains, and violent winds. With advances in forecasting and warning technology, timely evacuation, and accessible and adequate shelters, more recent research has focused on behavioral factors such as adequate receipt of warning messages, appropriate safety responses by citizens, and the appropriate use of shelters during the impact phase. The few impact deaths from hurricanes in the United States are largely attributed to roof collapse.

Postimpact investigations have addressed deaths and injuries that may occur during specific activities, including cleanup and the use of alternate sources to generate electricity. Risk factors for psychosocial conditions are also observed during the postimpact phase, as long as 5 years after the disaster has occurred.

Finally, displaced populations, often temporarily sequestered in designated sites, may live under conditions where sanitation and hygiene may be compromised owing to the large numbers of people living in an evacuation site. Maintaining safe and adequate supplies of food and water and monitoring communicable diseases are priorities for health management during this period.

Natural Factors

The hazards associated with cyclones center primarily on the effects of storm surge, violent winds, and rains. Almost 90 percent of all cyclone-related deaths are attributed to drowning from accompanying storm surge, which results from the motion of high winds on water. The rise in sea levels due to the storm surge may also result in the flooding of areas far inland *(5)*. Violent winds result in flying debris and structural

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collapse. Of 14 deaths directly attributed to Hurricane Andrew in Florida in 1992, preliminary reports indicated that 11, or 79%, occurred when structures collapsed on occupants *(45)*. Heavy, torrential rains may lead to flooding of inland estuaries and streams and may precipitate riverine floods and flash flooding.

Cyclonic events can also weaken structures and vegetation, such as trees, in the surrounding environs. Injuries may then be caused when such objects fall on people. Of 38 fatalities associated with Hurricane Hugo in Puerto Rico and South Carolina in 1989, 3 deaths were associated with falling trees that either directly hit a victim or struck a structure or vehicle, killing the occupant *(46)*.

In some cases, hazards associated with a secondary natural disaster, such as a tornado, may accompany the main event, or the cyclone. Of 17 hurricane-related fatalities in Louisiana after Hurricane Andrew, 1 was caused by violent winds during a tornado that was spawned from the hurricane before landfall *(18)*.

Human-Generated Factors

Human-generated risk factors for morbidity and mortality from tropical cyclones in both developed and developing countries include poor building design or construction, insufficient lead times for warning and evacuation, noncompliance with timely evacuation, and the use of inadequate shelter.

In developed countries such as the United States, building codes for hurricane-resistant construction have yet to improve in hurricane-prone communities. An estimated 126, 000 single-family dwellings and 9,000 mobile homes were destroyed or damaged after Hurricane Andrew struck South Dade County in Florida in 1992. Of the 15 deaths directly caused by the hurricane, 12 were wind-related *(10)*. Although a building code had been implemented since 1957, damages from this hurricane underscored the need for developing better designs for wind safety *(47)*. Mobile homes continue to be popular, particularly along coastal areas of the warm sunbelt region. Although residents of mobile homes were warned to evacuate, several deaths directly attributed to the forces of the hurricane occurred in mobile homes within the evacuation zone *(30)*.

Land-use patterns also affect the severity of impact of tropical cyclones. Although much is known about the hazards of cyclones along vulnerable coasts, the settlement of barrier islands and other vulnerable locations has grown tremendously in recent years and has placed additional people at risk, many of whom have had little or no experience with hurricane preparedness *(8)*. The problem is further exacerbated during weekends, holidays, and peak vacation seasons when populations in coastal communities can increase by 10- to 100-fold or more *(8)*. For example, according to the 1990 U.S. Census, the permanent population of Worchester County, Maryland, is 35, 000. Ocean City, a major regional tourist hub located in the county, attracted an estimated 350, 000 visitors during the Memorial Day weekend in 1991 and approximately 3.8 million visitors during the Labor Day weekend *(45)*.

Among residents of nursing homes and hospitals, evacuation is a major problem because of the lack of mobility and special requirements for adequate care among such patients. Evacuation of nursing home patients during Hurricane Elena in Pinellas County, Florida, in 1985 raised issues related to timely patient transport, inappropriate medical care and facilities in shelters, and equipment and supply needs of caregivers during the impact and postimpact phases *(48)*. The risks for injury and illness during evacuation have yet to be fully determined among people with special needs.

Deaths related to preparedness measures undertaken by the population have been observed before a cyclone's landfall. Many deaths have been associated with electrocution or drowning while securing property such as television antennas or boats *(16, 27)*. One death resulted from an impact injury in a motor vehicle crash during evacuation from areas under hurricane watch or warning *(18)*.

The building of enough transportation routes to evacuate residents and visitors in the event of a hurricane has not kept pace with increases in the permanent population of hurricane-prone areas and increases in the number of visitors to such areas (8). For example, only one highway exists to provide for the safe evacuation of the population of the lower Keys in Florida.

In Bangladesh, non-use of shelters contributed to the overwhelming mortality observed after the cyclone in 1991. From a sample of 1,123 people, an estimated 22% of those who did not reach a block or concrete structure perished in the cyclone. Deaths were highest among women older than 40 years of age (31%) and among children younger than 10 years of age (26%) *(49)*.

Fatalities during posthurricane cleanup activities are largely attributed to electrocution from improper use of generators, trauma from weakened structures or trees, and asphyxiation while entrapped under uprooted trees.

Lacerations and punctures, mainly from operating chain saws while clearing debris, are often observed in the postimpact phase. Results from a study of morbidity related to Hurricane Andrew using data collected at a pediatric emergency department suggested the potential for increased hydrocarbon or bleach poisoning among children in households involved in cleanup activities *(34)*. Public health recommendations point to the importance of observing adequate injury prevention and control measures in the aftermath of a hurricane, such as exercising caution during any cleanup operation where heavy equipment is in use.

The lack of electricity, a common phenomenon after a hurricane, may result in increased injuries related to the use of candles and generators. Burns and smoke inhalation from fires due to unattended open flames were observed after Hurricane Hugo in 1989 *(27)*.

Prevention and Control Measures

Although prevention and control strategies for cyclones are similar to those used for most hydrometeorological disasters, preventive measures feature a "window of oppor-

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tunity" before a cyclone makes landfall. During this time, occupants of areas under watch or warning may evacuate in a timely manner to seek safe shelter. Coupled with advances in forecasting and warning technology in recent years, adequate warning times for evacuation have allowed for the clearance of areas that would otherwise be subjected to the forces of a hurricane, thus decreasing mortality and morbidity. To date, prevention focuses on disseminating information, making appropriate decisions, coordinating warnings, and crafting more understandable warning messages *(9)*.

Appropriate Building Design and Construction Materials

In countries that are frequently affected by cyclones, such as Bangladesh and the Philippines, local and international authorities currently are investigating the use of appropriate building design and construction materials that are culturally appropriate to the region and that can withstand gale forces of hurricanes *(50)*.

Appropriate Land-Use Planning

Effective land-use planning can mitigate the adverse public health effects of cyclones. For example, structures with occupants who have special needs, such as the hospitalized, the institutionalized, and elderly people, should be located away from low-lying coastal areas in hurricane-prone areas.

Preparedness

Hurricane preparedness continues to play a major role in offsetting mortality or morbidity associated with the hazards of hurricanes. In some cyclone-prone areas of the world, notably the Western Pacific, the seasonal occurrence of typhoons creates a "disaster culture" for which preparation is almost habitual. As a result, typhoon-related mortality and morbidity are generally low. In contrast, adequate preparedness may be difficult to achieve in some areas of the United States, where 80%–90% of people living in hurricane-prone areas have never experienced a major hurricane *(45)*.

Warning

The meteorologic properties of cyclones, such as well-defined paths, allow for more effective watch and warning systems, particularly in the southeastern United States. In 70% of hurricanes, paths can be forecasted 24 hours in advance on the basis of speed and direction during the previous 24 to 36 hours *(5)*.

Because predictions lead to expensive preparations and disruptive evacuations, however, the error factor becomes a dilemma for forecasters *(5)* and, ultimately, for public health officials. Those issuing warnings must balance safe and timely clearance of an area with the potential that such predictions have for causing economic losses incurred

by the disruption of commercial and other business activities. However, a degree of "overwarning" (defined as the tendency to add more time to the regular "warning time") may be necessary due to (1) increased population densities, especially in high-risk coastal areas; (2) the limitations of forecasters to know the exact timing, strength, and location of impact of a storm; (3) public reluctance to evacuate (due in part to the costs mentioned above); and (4) the potential for loss of lives during a hasty evacuation due to heavily congested traffic. An estimated minimum of 30 hours is now needed to evacuate people from Galveston Island, Texas; the Florida Keys; New Orleans, Louisiana; and Ocean City, Maryland *(9)*. Unfortunately, "overwarning" (i.e., long and frequent population clearance times) presents a dilemma because overwarning too often could eventually detract from the credibility of hurricane forecasters and result in delayed public evacuation.

Adequate forecasting is also based on the width of an area under hurricane watch or warning and changes in storm category (e.g., from Category 3 to 4). For example, expanding the width of the area under warning for Hurricane Elena in the Florida Panhandle in 1985 led to considerable loss of income—an estimated $10 million for every increase of 20% in the size of the area under warning. Raising the storm category from 3 to 4 in the Galveston-Houston, Texas, area would necessitate the evacuation of an additional 200, 000 people *(8)*. It follows that overwarning by wide margins could reduce public credibility for evacuation warnings *(8)*. Any changes in warning zones or storm categories that result in evacuation could result in substantial public health problems as a direct result of large-scale population movements. Likewise, decisions to remain in place rather than to evacuate potentially increase risks for injury, illness, or death in a hurricane.

Evacuation

Adequate emergency planning should allow for the safe evacuation of coastal and low-lying areas and adequate in-place sheltering for temporary increases in population. Using conventional horizonal evacuation to safer inland areas rather than vertical evacuation (e.g., in-place sheltering on higher floors of multistory buildings) is a possible mitigative strategy for ensuring the safety of people living in coastal communities *(51)*.

Behavior

Given an impending cyclone, appropriate behavior invariably leads to greater safety. Compliance with evacuation orders from public officials obviously results in a greater chance for survival. Results of a study of 1,123 people after the cyclone of 1991 in Bangladesh showed that all people who sought refuge in brick or concrete shelters survived, whereas nearly 22% of those who did not seek refuge died *(49)*.

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Adequate Shelter

Shelters that are appropriately constructed and accessible to the public, particularly in developing countries, may enhance survival. The use of shelters in coastal villages in Bangladesh during the 1991 cyclone was a major determinant of survival. To prevent deaths and injuries in future cyclones, additional shelters have been planned for construction in coastal communities in Bangladesh *(49, 52)*.

Continuing Public Education

Perhaps the single most important prevention measure for cyclones is public compliance with evacuation orders. The public should also be informed of the margins of error in forecasting a cyclone's intensity and area of impact. Moreover, the public should be aware of the variability of a cyclone's intensity, which is subject to changing meteorological conditions.

In the aftermath of a hurricane, guidelines for preventing or reducing health effects are issued by local health departments, cooperative extension units, or emergency management agencies. Prevention guidelines for individuals and households in the aftermath of a hurricane are found in the CDC pamphlet *Hurricane: a Prevention guide for maintaining your personal health and safety (53)*.

Needs Assessment

Because a cyclone's strong forces can affect a large geographical area, the impact in the disaster zone tends to be widespread. Rapid needs assessments of areas affected by a hurricane should be conducted in order to determine appropriate health and medical requirements in the affected community. Results of these assessments would assist in directing appropriate resources and services to an area. A typical needs assessment would be repeated over time, since needs are likely to change when people relocate or move back and when services are restored in the areas of impact. Also, needs assessments may be performed to determine the adverse affects cyclones have on the public health infrastructure. Such assessments may also be modified as appropriate to the situation; in one postcyclone investigation epidemiologists assessed community nutritional status and agricultural and fishing potential in a developing country *(54)*.

Surveillance

Cyclone-related deaths, illnesses, and injuries and their circumstances should be monitored so that appropriate prevention or citizen-safety guidelines can be issued to the public. Active and passive surveillance systems should be based on a variety of reporting sources, including hospital emergency departments, shelters where medical care

is provided, free-care sites, private health care providers, and medical examiners' and coroners' offices. Further, special surveys may be undertaken to identify any increases in postcyclone vector populations, particularly in areas where arboviral diseases may be endemic.

Response and Recovery

Appropriate response in the aftermath of cyclones is similar to that used in postflood situations and other hydrometeorological disasters *(55)*. Major issues involve the following: (1) water quality; (2) food safety; (3) sanitation and hygiene; (4) precautions during cleanup activities that may lead to injuries; (5) potential immunizations—for example, maintaining current tetanus immunization as determined by local officials; (6) protective measures against vectors, such as mosquitoes, rodents, and other wild animals; (7) chemical hazards; and (8) mental well-being, such as stress reduction and counseling, for both victims and responders. Issues such as water quality, food safety, sanitation, and hygiene are especially germane among displaced people who are temporarily housed in densely populated quarters where the potential for transmission of disease may be exacerbated *(56, 57)*.

Critical Knowledge Gaps

Although the cyclone literature describes postimpact mortality and morbidity and outlines risk factors, several important gaps in the epidemiologic knowledge base need to be addressed. Still needed are:

- description of needs in the aftermath of cyclones in inland and coastal communities
- identification of determinants of shelter use, particularly in cyclone-prone cultures
- identification of risk factors for mortality or injury among shelter-seekers
- identification of risk factors for death, illness, or injury among groups with special needs, such as hospitalized or elderly people
- association between mortality or injury and the major meteorological elements that typify a particular cyclone, such as degree of storm surge and wind strength
- association between mortality or injury and the structural integrity and relative wind resistance of buildings
- description of the long-term health effects of cyclones, such as nutritional deficiency and birth defects
- evaluation of the effectiveness of prevention and mitigation measures (e.g., coastal afforestation, the planting of trees on previously unforested land) on public health outcomes

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Methodologic Problems of Epidemiologic Studies

The following methodologic problems have been identified in past cyclone-related studies:

- Case ascertainment for cyclone-related conditions. Defining a cyclone-related death, injury, illness, or condition has yet to be uniform and consistently applied to cyclone-related studies.
- Misclassification of cyclone-related health and medical conditions. Often, local officials such as medical examiners, coroners, and personnel in hospital emergency departments decide whether or not an event is "hurricane-related."
- Selection bias can be introduced when investigators monitor cyclone-related health effects. Results are often generalized from data sources that include several of the following: (1) hospital emergency departments, (2) temporary shelters that provide health and medical care, and (3) free-care sites operated by the American Red Cross and other private voluntary organizations. It is important to know what roles, if any, private health care providers and other parties such as the military are contributing to overall health effects when attending to cyclone-related illnesses and injuries, even if only for a limited time. Moreover, many external aid groups commonly enter affected areas to provide medical care and leave without reporting or even documenting the types of injuries and illnesses they treated.
- The time period for monitoring cyclone-related deaths, illnesses, or injuries must be standardized in order to ensure consistency when comparing health outcomes for different disaster events. Because most illnesses or injuries tend to be acute, local officials normally use a period of 1 month after a cyclone's impact in which to monitor medical conditions *(26, 35)*. In one extreme case, 1 death due to direct impact occurred approximately 6 months after Hurricane Andrew passed through South Dade County, Florida, in August 1992 *(58)*.

Research Recommendations

- Surveillance of cyclone-related deaths, diseases, and injuries should continue through the response and recovery periods. Gastrointestinal morbidity, respiratory illnesses, and injuries related to cleanup activities are among the common conditions that should be monitored, particularly after a hydrological disaster. Should any changes from precyclone conditions be detected, then investigations of risk factors related to the condition should be initiated.
- In areas where mortality occurs during the impact phase, systematic studies should be undertaken to determine the effectiveness of warning systems.
- Systematic studies should be undertaken to estimate the association between deaths

and injuries and the structural integrity and relative wind resistance of buildings. Because high winds are instrumental in causing morbidity and mortality in some hurricanes and because evacuation zones are primarily determined by the damage potential of storm surges, studies should address the association of structural collapse with deaths and injuries.

- Systematic studies should be conducted to determine risks for illness or injury during evacuation at different points in time during the population-clearance process.
- Among populations with special requirements, such as the institutionalized, systematic studies should be conducted to determine any adverse health outcomes during horizontal or vertical evacuation.
- Systematic studies should be undertaken to determine any differences between risks for injury or illness in coastal communities and inland communities (e.g., during both the impact and postimpact phases) *(38)*.
- Systematic studies should be conducted to assess the short- and long-term effects of cyclones on the mental health status of the affected community.

Summary

Tropical cyclones are among the most destructive of natural disasters. Because cyclonic storms tend to be wide, their effects after landfall may encompass a large area. Hazardous affects of cyclones arise from violent winds, torrential rains, and storm surges. Other hazards usually present themselves during the preimpact preparedness phase (e.g., securing potential high-velocity projectile objects) and after the passage of a tropical storm during cleanup activities (e.g., operating chain saws and electric generators).

Developments in forecasting and warning technology have contributed much to ameliorating the adverse health effects of tropical cyclones. Better and more understandable communication of information from meteorologists to the community may result both in more timely evacuations of inhabitants in areas under hurricane watch or warning and in subsequent more appropriate relocation to safe shelter.

To strengthen community hurricane preparedness, appropriate evacuation behaviors, given certain clearance times and storm categories, must be determined more fully. Safe shelters should also be identified both in areas for evacuees and in areas under hurricane watch or warning. Warning information must also be communicated clearly to the public.

After impact, the health effects of tropical cyclones, like those of floods, are dependent on water quality, food safety, sanitation and hygiene, precautions during cleanup activities, potential immunizations as determined locally, protective measures against vectors, potential release of toxic substances, and mental health sequelae.

Assessing health needs and services in affected communities; maintaining surveillance of deaths, illnesses, injuries, and, if necessary, vectors; and monitoring the quality

of water and wastewater systems should continue in the aftermath of a cyclone until predisaster conditions are restored in the affected area.

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